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ABSTRACT

As part of an ongoing effort to understand the processes people employ in reading technical material and the ways in which computer based job aids can assist people in doing complex tasks, a study was conducted to determine how subjects engaged in an assembly task use a detailed and hierarchically organized information structure (Hypertext) to meet their information needs. The computer based job aid used explains how to assemble a miniature loading cart and allows viewers to call up text seen earlier or Hypertext definitional and graphics frames. Subjects were 20 adults, including electrical engineers, stockboys, secretaries, graduate students, and teachers. It was found that subject performance on the assembly task was noticeably better than in previous studies employing the same task; subjects as a group selected graphic information most often, dictionary information next, and sometimes made rechecks of text or nontext information; almost all the possible information sources were used at least once by a substantial proportion of subjects; responses to different sites in the assembly information program varied widely; subjects differed widely in the number and patterning of information requests made; and individual online problem solving strategies included different combinations of input translation, selection and application of a problem solving method, regrouping, and generation of subgoals. It was concluded that it may be useful to include a variety of kinds of information in a technical information system for job aiding, and to allow subjects a high degree of control over requests for information. A 12-item bibliography is provided. (ESR)

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COMPUTER-BASED JOB AIDING: PROBLEM SOLVING AT WORK

David E. Stone
Barbara A. Hutson

Technical Report No. 11

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This research is part of an ongoing effort to understand the processes people employ in reading technical material and the ways in which computer based job aids can assist people in doing complex tasks. The central questions were "Where people have easy access to many kinds of information what information do they select to help them do the job? How do people vary? How does

information selection differ across sites in the text and graphics?" This report provides a description of the final work in this area sponsored by our contract.

Computer Based Job Aiding:
Problem Solving at Work

The nature of work in many occupations is changing. Routine computation and information gathering are becoming less critical skills for workers. No rows of men in eyeshades and cardboard sleeve-protectors laboriously penning entries into ledgers. No girls pushing carts through file rooms. Fewer mechanics and repairmen poking and probing, because much of the routine diagnosis will be aided by computer-directed diagnostic routines or by built-in diagnostics in complex equipment. And, soon, fewer data processors feeding endless raw material into computers--much of the needed information will already be stored, and more new data will be entered untouched by human hands. There'll be less need for people to talk to computers because more computers will talk to people.

What will be left? Problems. Problems to be solved, and not the easy ones--they'll be handled by routine programs. But there will always be problems that just won't fit, problems newly invented, and problems whose very nature is undefined. These will need a human problem solver. The critical skills for such a worker will not be to gather or compute information but to select information relevant to the problem and to manipulate the existing information structure, to turn it and twist it to bring into focus the facet needed for this problem. More work, then, will involve human problem solving, aided by and operating on computer based information structures.

In preparing people for this kind of work and preparing information structures to aid them at work, we need to know what workers need to know. Given a rich information structure and a problem to be solved, what information do people select? And how does that information selection fit into the larger problem solving process? This paper will not attempt to solve these broad problems in one jump, but will make a start by defining a context within which to view the problem, describing some strategies for studying information selection in computerized job-aiding systems, and presenting initial findings.

Studying Problem Solving

In studying problem solving we can draw upon a rich body of literature, particularly the work of Newell and Simon (1972) and associates. This framework, extended and refined by these authors and others, has been applied to a variety of content areas. There has, however, been little examination of the on-line problem solving strategies of individuals using a computer based job aiding procedure. The Newell and Simon model of human problem solving seems likely to be useful in studying these processes, but although this model has great power and is potentially applicable to a wide variety of phenomena, it must be instantiated anew in each new setting.

While processes such as input translation and selection of a problem solving method probably occur in all settings, these general processes or others may appear in different forms and be given different weightings in various settings. The problem solving processes should be defined within a specific setting.

The setting to be considered here is a computer based job aiding procedure. Subjects read from a display terminal the directions for a procedural task, construction of a model loading cart. It was possible simply to read and carry out each of the steps explained in a series of instructional (text) frames. If, however, the subject needed more information about nearly any term, procedure, or graphic display, he/she could access further information simply by "marking" the screen with a light pen.

This was made possible by analyzing the expected information needs and designing brief, readable text and graphics, likely to be understood by most users (Stone, 1977). The next step, though, was the key--differentiating this job aiding procedure from many others, including previous studies in this research program. The technical information system was organized as Hypertext™, incorporating the previously available surface level text as the central level in a three-level hierarchy. The more detailed level consisted of definitions of terms; some definitions were verbal only, others included both text and small black and white or colored graphics of parts, their spatial orientation, or operations to be performed on the parts. The more global level here consisted of graphics. (In other cases this global level might be conveyed verbally.)

[Insert Figures 1 and 2 about here]

The three levels in the information structure were linked. A user operating on the level of surface text (the sequence of readable but succinct steps in assembling the loading cart, some of which are shown in Figure 1) could touch with a light pen almost any term on the screen. (See Figure 2). The program would branch to a frame defining the term, and the user could then touch the word Back to return to the frame in the surface

text. Similarly, the user viewing a frame in the surface text could at any point touch a box on the screen in order to view a graphic illustration of the object (Figure 2). From a frame in the surfact text the user could move to graphics, to dictionary, forward to the next frame, or backward to view a previous frame of the surface text.

[Insert Figure 3 about here]

Responses to Blocks in Information

Even when instructions in a task are informative and well organized, an information block (such as failure to understand the referent for a technical term or the intended orientation or relationship of two parts) may occur. What responses are possible? Ordinarily, in encountering an information block in written text a reader has only a few options--to plunge forward, either ignoring the block or hoping to resolve it with information later in the text, or to move backward to review earlier information that might provide clarification.

With the use of Hypertext, however, the reader's potential responses are increased. Figure 4 represents these options schematically. Faced with a block in information, the user can move forward (in which case we may not know a block has occurred except through performance deficits or later re-checks to that frame), move backward to recheck earlier text or Hypertext, move down (an arbitrary designation but psychologically useful in visualizing information moves) to check the definition of a specific technical term or even the meaning of a familiar word in this context, or move up to a graphic view of the assembly completed to this step or a graphic overview of the completed object.

[Insert Figure 4 about here]

The levels of the hierarchy available as responses to blocks in information thus include not only the surface text of directions but a more detailed level and a more global level. This conception of the hierarchical structure of information is implicitly rooted in Frederiksen's (1975) analysis of discourse processes, although those notions are operationalized in a new way.

Information Search in Technical Literacy as Problem Solving

The dimensions of the problem to be solved by users of this technical information system can best be understood by considering the several levels of goals, the problem solving processes that can be applied in this context, and the means by which these processes can be observed or inferred.

The overall goal set by the researchers in this assembly task is to complete the correct assembly of the miniature loading cart. Subordinate to that goal are the subgoals of completing each of the sequentially arranged text frames, each guiding transformation of the object from one state to the next. (At each step there are also 1 to 3 substeps to be checked off by touching the light pen to the screen as completed, but our analysis focuses on the 16 frames for surface text; the 17th frame requires no action.) Subordinate to completion of a given step are the information-seeking moves undertaken within that step. While the overall goal and the subgoals are the same for all subjects in this study, the information each subject requests to enable himself/herself to complete each step may vary widely.

The focus in this study is on the problem solving strategies individuals use in overcoming information blocks. Little emphasis is on the evaluation and selection processes that guide a given user in selection of information from the information structure provided, from his/her own information structure, and from the object in hand; emphasis is on the directly observable moves to various parts of the computer based system.

Newell and Simon (1972) p. 88) described aspects of the overall organization of an information processing system in this way:

1. Input translation, producing in the problem solver an internal representation of the problem (in this case, the information block) to be solved. "The problem solving then proceeds in the framework of the internal representation thus produced -- a representation that may render problem solutions obvious, obscure, and perhaps unattainable."

2. Selection of a problem solving method: "A method is a process that bears some rational relation to attaining a problem solution, as formulated and seen in terms of the internal representation." In this case the available methods may include searching the total information structure (prior knowledge, surface text, Hypertext, and the object itself), drawing inferences, self-monitoring, and integrating the information bearing upon comprehension of a particular point.

3. Application of the problem solving method to the information block. "At any moment, as the outcome either of processes incorporated in the method itself or of more general processes that monitor its application, the execution of the method may be halted." The information block may be overcome, apparently overcome, or left unresolved.

4. Regrouping if necessary. Newell and Simon note (p. 88, footnote) that "The continuous flux of new information from the environment may offer new solution possibilities or demands that cause the problem solver to interrupt (his/her) current activities to try different ones." They also state that "when a method is terminated, three options are open to the problem solver: (a) another method may be attempted, (b) a different internal representation may be selected and the problem reformulated, or (c) the attempt to solve the problem may be abandoned," at least for the moment.

5. Generation of subgoals. While the method is being applied, new problems may be recognized. "The problem solver may elect to attempt one of these" or may set aside new subgoals, "continuing instead with another branch of the original method."

In order to understand the problem solving processes engaged in during computer-assisted technical literacy, information seeking strategies employed during an assembly task were analyzed in terms of overall group frequencies and individual patterns. The questions to be answered were:

1. Is performance (with Hypertext availabel) greater than in previous studies?

2. What is the relative frequency of various types of information requests across the group?

3. How do programs differ in the relative frequency of various types of information requests?

4. How do individuals vary in information selection and use?

   a. in relative frequency of various information requests

   b. in patterning of information requests

Method

Sample

The subjects in the sample included 20 adults ranging widely in background, including electrical engineers, stockboys, secretaries, graduate students and teachers. This allowed a test of the Hypertext system's ability to respond to the information needs of users ranging widely in background.

Materials and Equipment

The materials used include 17 frames of directions for assembling a miniature loading cart from Fishertechnick (Leg-like) blocks. This surface text presented each step clearly and concisely,as shown in Figure 1. (The full text and all segmented graphics are available in Stone & Crandell, 1982.) Each text frame, however, gave the viewer the option of rechecking text seen earlier or branching into Hypertext. By touching with a light pen almost any substance worked on the screen, the viewer called up a frame that defined the term or explained its meaning in that context; often the definitions were accompanied by small illustrations of the part or operation defined.

The viewer also had the option of viewing several types of graphics. By touching one of the boxes centered below the directions for each substep, the user could view an illustration of the loading cart as it should appear at that step in the assembly process. Or, by touching a box in the upper left corner, the user could, at any point in the program, branch to a graphic depicting the completed object.

The detached display screen was linked to Hazeltine's TICCIT (Time-shared Interactive Computer Controlled Information Television). A central feature of the system for this purpose was the Hypertext ™ Display System. Technically, this term includes the organization of both surface text and the supplemental graphics and definitions, though we will at times speak of contrasts between text and Hypertext. Fuller description of this system is given in Stone and McMinn (1982); and in Stone, Israelite, Mudrick, and Hutson,(1983).

Data-gathering Procedures

Each subject, tested individually, was seated at a computer display console equipped with a light pen. The parts needed to assemble the miniature loading cart were spread out on the table. The examiner explained the purpose of the study and led the subject through the introductory phase of the program, which explained and illustrated the information search options available. Then, as the subject progressed through the steps of the program, the examiner made notes on his/her performance. An internal tracking program recorded and later printed out the sequence of numbers of the frames viewed by each subject.

Data Analysis Procedures

The key variables tabulated were number of requests for graphics (overview or segmented) definitions, or rechecks. Based on the conceptualization of information blocks and information search strategies discussed earlier, the computer's internal tracking records of the sequence of frame numbers viewed were transformed (manually in this case, though the TICCIT system could be programmed for this task) into visually salient graphic profiles of each subjects' performance. This facilitated explicit description of each move by each subject, yet made it easy to detect the larger patterns within which individual moves were embedded. The next

step was to tabulate relative frequency of various information requests for each subject at each program frame.

Results and Discussion

First we will examine performance, then the overall distribution of various types of information requests across all subjects and all program frames. Next we will break down the distribution of requests by program frame (reflecting type of information block), and then by individual subjects. Individual differences will be examined at two additional levels, the overall pattern of information seeking moves by selected individuals and the problem solving strategies that seem to be reflected in these patterns.

Success on Performance of the Assembly Task

One variable on which subjects hardly differed was success on the task. The directions were designed to be clear and readable, yet previous studies using the same surface text (Stone & Glock, 1981) showed that two-thirds of the subjects completed the task with some uncorrected errors. In this study, with the addition of Hypertext, almost no errors were uncorrected by the end of the task. Nearly all subjects succeeded, but they succeeded in different ways.

The technical information system made possible by the Hypertext Display feature embedded in the TICCIT system in effect provided for each individual a different program tailored to his/her unique preferences. One person was able to view many supplemental frames while another saw none; one to view more definitions or graphics than another. This carries adaptive instruction to great lengths and is a promising approach to apply when users are potentially diverse. An expert using such a system will encounter little clutter, while a novice finds multiple support systems, some well matched to his/her preferences for the form and content of information.

Overall Frequency of Requests for Various Information Sources

After completing the assembly tasks in frames 1 - 16, subjects found in frame 17 an expression of thanks for their participation and an invitation to explore the system, rechecking text and Hypertext if they wished. Some of the subjects exercised this option, most for just a few moves and others for an extended search. An earlier report (Stone, Hutson & Fortune, 1983) based on a subset of this sample, included in analysis the information requests during both assembly and exploration phases. Requests for graphics and definitions during exploration were proportional to the requests during the assembly, though the percentage of rechecks was almost by definition greater during exploration. The present analysis will include only the information searches during assembly.

[Insert Table 1 and Figure 5 about here]

The surface text frames were viewed by all subjects. As indicated in Table 1 and Figure 5, apart from surface text, 47% of all requests were for verbal information, 53% for graphic. The verbal requests included definitions (37%) and rechecks of previous text (10%). The graphic requests included segmented graphics (44%), and overview graphics (9%). On the whole, while there were more requests for graphic information than for verbal information (beyond the surface text viewed by all subjects), roughly the same proportions of verbal and graphic requests were maintained across most frames.

Some definitions were used much more frequently than others. It would certainly be possible to reduce the lexicon available, but a definition (either the meaning or the specific referent) needed by no one else may be critical to success by a few individuals. This may be particularly true for men or women with little previous technical experience or those for whom English is

a second language or for foreign nationals who are receiving technical training. In a new study of community college students, about one-third were speakers of English as a second language; we will examine closely the kinds of terms for which they requested definitions.

Prevalence of Various Types of Information Requests

Even when a rich technical information system is provided, the question might be raised, "But is all that necessary?" The second aspect of analysis of overall information selection addressed that question, examining how widespread was use of a given type of information: Did overall means result from many requests by a few individuals, or did many subjects request a given type of information at least once? The answer seems to be "Both." While some individuals, as discussed later, made much higher use of some information sources than did others, almost all information sources were used at least once by a substantial proportion of subjects. The surface text was used by all of the subjects. (In this case they had to check one or more steps completed on each frame in order to move to the next surface text frame.) Nearly as many subjects requested segmented graphics and definitions at least once. The majority requested overview graphics and rechecks at least once.

Did they need all these types of information? We can only answer that the subjects apparently felt that such information would be helpful in solving a problem encountered during the assembly task. It would be possible to reduce the number of types of information available, but at the potential cost of reducing adaptability of the job aiding procedure to a wide range of individual differences.

Differences in Relative Frequency of Information Requests Across Program Frames

The sixteen program steps were in effect sixteen different problems to be solved. Some were more difficult than others, and some were difficult for different reasons than were others. Overall difficulty is reflected in the total number of information requests at each frame (Table 2 and Figure 6). Information requests were most common for frames 4-5, 10-11, and frame 16.

(Insert Table 2 and Figure 6 about here)

The total number of information requests per frame ranged from a low of 2 to a high of 65. Requests for graphic information were slightly more frequent than requests for verbal information at most frames. The categories of graphic or verbal requests can be analyzed more finely to examine the patterns for specific types of information source. Although the small numbers in these subcategories make it unwise to overinterpret, exploration may provide insights (about sources of difficulty, types of information search strategies, and their relationship) that can guide both research and practice.

The overview graphic was requested most frequently in frames 4-5, 9-10, and in the last frame. There were no requests for this information source during frames 12-15, at which point the general contours should be known to the user either through previous views of the overview graphic or segmented graphics or the object in hand. Of the requests for verbal information, requests for definition were three times as frequent as for rechecks. Both types were selected on frame 5, but there were more requests for definitions on several frames. On frame 16, there were 30 requests for definitions and only 2 for rechecks.

The nature of the requests differed across program frames. Some trouble spots usually provoked requests for only one kind of information source. On the other hand, frame 5, frequently an information block, elicited a variety of information requests, including 28 requests for segmented graphics, 24

requests for definitions, 4 requests for overview graphics, and 10 rechecks of text.

(Insert Table 3 and Figure 7 about here)

Frame 5 provoked more text rechecks than any other, as though the new step made users realize that there was something earlier they hadn't understood (Table 3). The two clusters of frames from which greatest number of rechecks started were 4-5 and frame 10. The patterns of rechecks in Figure 7 give a closer look at rechecks as information search strategies and the sites that provoke them. In this display the arrows originate in the frame where users felt the need for clarification and the arrow heads indicate the frames to which they returned for clarification. (In longer sweeps they may also have gained some information from the frames viewed enroute to the terminus of the recheck, but apparently not enough to stop the search.) Four of the subjects made no rechecks, while some made extensive use of this option. Many of the rechecks made were brief, such as subject 1's three separate one-step rechecks, but a few were longer, one recheck covering nine frames. The rechecks were predominately for surface text, but included here (though not double-counted in analysis) are a few excursions to definitions (shown with a tick below the arrow) or to graphics (shown with a tick above the arrow).

The largest number of rechecks (Table 3) began at frame 5, signalling a problem, and the largest number terminated at frame 4, suggesting that information in this frame helped to solve a problem. Though many of the rechecks at frame 5 terminated at frame 4, there was not a point-to-point correspondence. Some of the rechecks from frame 5 passed through frame 4 and continued in reverse to earlier frames, and other rechecks begun at frames 7 and 10 terminated at frame 4. For other pairs of frames, though, there were apparent links--rechecks beginning at frame 3 all ended at frame 2, rechecks beginning at frame 8 ended at frame 7, and rechecks from frame 13 ended at frame 12. Most of the rechecks that involved requests for graphics or definitions centered on frames 4 and 5, and a substantial proportion of these were by the same

individual. Both the small number of text rechecks and the uneven proportion that were repeats by the same user suggest that while this is a dimension useful in describing individual differences, use of text rechecks on a given step as a signal of program problems would require a larger sample. Once a problem spot has been identified by other means, though, analysis of recheck patterns may guide fix-up strategies.

Individual Differences in Frequency of Various Information Requests

Individuals differed widely in the apparent difficulty (as indexed by number of information requests) they experienced across the whole task and at specific program sites, and in the types of information they requested.

One source of difference was in relative dependence upon graphic versus verbal information to supplement the surface text. One person requested graphic information 19 more times than he/she requested verbal information. The most verbally oriented person had a ratio of 3 graphic requests to 33 verbal. One person asked for neither type of information.

There were also differences in individuals' use of specific categories. Several people made 15-18 requests for segmented graphics, but just as many made only 2 or 3 such requests and one person made none. The number of definitions requested by an individual ranged from 0 to 30, and the total number of information requests ranged from 0 to 46.

Reconstruction of Individual Information Search Patterns

Several individual profiles are schematically represented in Figure 8. Movements from left to right represent forward moves through the 17 frames of the surface text, checking off various steps completed, in order to gain access to the next frame. Requests for graphics are represented as movements upward. Requests for dictionary are represented as movements downward. Rechecks, requests to review previous frames, are represented as movements from right to left.

Given the TICCIT system's internal tracking programs, it is possible to reconstruct the exact sequence of information moves made by an individual and, within limits, to infer some of the problems encountered and solutions attempted.

Subjects varied widely in the number, kinds, and patterns of information requested. Subject 7, for example, made no requests for any supplemental information during the assembly phase, though he requested two graphics during the later exploratory phase (not included in the analyses in this report). Subjects 10 and 14 requested a number of graphics but only one definition. Subject 8 had a balance of graphics and definitions.

While none of the subjects shown in Figure 8 made rechecks during assembly, all of the subjects shown in Figure 9 made some use of rechecks. During the assembly phase, though, their rechecks were limited to the immediately prior frame. In most cases the rechecks were to text, but for subject 12, who made extensive use of definitions, one recheck was also for a definition, and for subject 4, who made extensive use of graphics, the two rechecks were also for graphics. The subjects shown in Figure 10 show more complex patterns, with more extensive rechecks during assembly. Visual inspection of some profiles suggests that frames 4-5 and 9-11 are provoking search strategies, sometimes requiring sampling or coordination of several information searches.

With a little analytic license, it is possible to reconstruct the information search procedures each individual displayed. Subject 3, for example, requested a moderate number of defintions and segmented graphics (but not overview graphics). Faced with a problem at frame 3, 4, and 5, though, he seemed to rely upon rechecks of text. At frame 4, this individual requested a related segmented graphic, rechecked frame 3, then moved ahead through frame 4 to frame 5.

Here he requested the related segmented graphic, rechecked frame 4, then moved through frames 5, 6, and 7. At this point, though, feeling unsure, he once again returned to frame 4, but then moved forward steadily, with no no further information requests to frame 9. From this point through frame 15 he made one or two requests at each frame. At frame 16 he requested definitions of "insert" and "grooves", and a repeat of frame 15, then moved to frame 17, completing the assembly task. Following frame 17 he did sweep back to explore the earlier trouble spot. (This exploration is not included in the analyses in this report.)

Subject 5 used, during the assembly phase, 8 requests for defintions, 7 rechecks to text plus 1 for graphics, and 5 requests for graphics. (There were other requests during the exploratory phase.) In trouble spots he tended to use a multi-media search, a variety of information search options. At frame 4, for example, this individual rechecked to frame 3, moved ahead through frame 4 to frame 5, rechecked to frame 4, viewing the related graphic, moved ahead to frame 5, back to the text in frame 4, ahead to frame 5 to check twice the definition of the term "angle block", back to frame 4, ahead to frame 5 for the same definition. From here he returned to frame 5, checking the definition a third time, requested the accompanying graphic and moved on steadily through the next few frames without any information requests. At frame 10 he engaged in a less extended search, but again used several kinds of information. After finishing the assembly task at frame 16 this individual returned to explore several points, requesting several graphics and one definition that had not been requested during the assembly phase.

These "snapshots" provide an intriguing view of the range of strategies subjects can employ in mastering directions for an assembly task, given a variety of kinds of information available upon request. We'd ideally like to have an "x-ray" of the covert processes, yet even in these less-than-perfect reconstructions, combined with observations and with comments from or informal debriefings with some subjects, we can see some patterns.

Discussion

This report is part of an ongoing effort to understand the processes people employ in reading technical material and the ways in which information engineering can facilitate those processes. This study provided a detailed and hierarchically organized information structure (Hypertext) as part of a computer assisted job-aiding procedure for an assembly task. The central questions were "Is performance (with Hypertext available) greater than in previous studies?" "When people have easy access to many kinds of information, what information do they select to help them do the job?" "How do program sites (information blocks) differ?" "How do people vary?" and "How are problem solving strategies displayed during computer based job aiding?"

Performance on the Assembly Task

Performance was noticeably better than in previous studies employing the same task. Crandell & Glock (1981) for example, presented this task with text and/or graphics on separate slide projectors. They found that the percentage of subjects (community college students) with errors uncorrected by the end were 100% for those who viewed text alone, 91% for those who viewed graphics alone, and 75% for those who viewed both. In the present study, employing the same text and graphics (though graphics in their study were "busier" than those in this study) plus definitions in a rapid access, user controlled and

computer based information structure, only one subject (5%) who had an uncorrected error -- one flat plate in the back was in its proper place but backward.

This suggests that when people can get the information they need when they need it, performance on procedural tasks is facilitated. But since people vary in the information they feel they need, it may be useful to have more information (and more forms of information) available than any one person is likely to need, yet to keep the surface text uncluttered in order to avoid information overload for those who don't need that information.

This study, however, did not directly compare performance with and without Hypertext. At this point we could not rule out the possibility that the enhanced performance was due simply to difference in subjects, though the subjects in this study ranged widely in background; some were considerably less familiar with technical material than subjects in earlier studies and some were not. A recently completed study using this procedure with community college students should help to clarify this point.

The study was on one level the application of a new variant of a job aiding procedure for a procedural task. On another level, though, the breadth of information available to subjects, the fact that subjects could select the information they felt they needed, and the opportunity to monitor closely subjects' information selection at each frame, made it possible to describe overall information selection patterns and to examine variability across subjects and across program frames. This in turn made it possible to explore the applicability of the model of information search in response to information blocks, embedded within the broader framework on on-line problem solving.

Kinds of Information Selection

Subjects as a group selected graphic information most often, dictionary next, and sometimes made rechecks of text or nontext information. Of the types of graphics available, the most frequent requests were for segemented graphics depicting the object as it should appear at a given point in construction. The next most frequent requests were for definitions. A few dictionary items were requested by a substantial proportion of subjects, while other items were requested by only one or two subjects. Rechecks to previous texts, not used by all subjects, were sometimes brief, returning to the previous frame.

Differences Across Program Sites

Responses to sites in the text differed widely. The sixteen program steps were in effect sixteen different problems to be solved. Some were more difficult than others, and some were difficult for different reasons than were others. Overall difficulty is reflected in the total number of information requests at each frame. The number of information requests per frame ranged from 2 to 65. Information requests were most common for frames 4-5, 10-11, and frame 16.

The structural difficulty and invisibility of two of these segments may be reflected in the fact that requests for graphic blowups were greatest at frames 5 and 10. At frame 16, though, far the largest proportion of requests was for definitions of one or two terms whose meanings or referents were unclear. Some frames were the starting point for far more rechecks and information requests for Hypertext than were others. The distribution of information requests may be useful, as discussed later, in on-line debugging procedures, making software more effective and less costly.

We have at this time only a partial picture of the link between type of information block and type of information search, but some tentative generalizations may be advanced. Three major forces seem to determine the number and kinds of information searches made by a given subject at a given information block in this assembly task. One force, influencing total number of requests at a given point, is the overall difficulty of a given step. Steps 4 and 5, 10 and 11, and 16 on the whole provoked a relatively large number of requests, while steps 2 and 15, for example, provided few.

A second force influencing both number and type of requests is individual preference. This is based on prior knowledge (influencing subjective difficulty), general willingness to seek information and preference for particular kinds of information. One individual, for example, made no requests at all, while another made almost 50. One relied primarily on graphics and much less on verbal information, while another made 33 requests for verbal information and only 3 for graphics.

A third force seems to involve task demands. Steps in this assembly procedure differ in the kinds of problems they present. Steps 4 and 5, for example, may be difficult primarily because they involve the joining of two subassemblies, for which a spatial-graphic overview is likely to be especially useful, though some need for definitions is also present. Steps 9 and 10 provoked requests both for graphics and for definitions. These steps involve the joining of two subassemblies, described explicitily but not necessarily clearly in the text. Two other problem sources may be involved here -- invisibility and ambiguity. The joint is not entirely visible from the segemented graphic or overview graphic, and some of the terms used seem easy enough, but subjects may not be sure what they refer to.

The general approach in this research program has been to observe what happens in a moderate-fidelity simulation, rather than to manipulate the dimensions of that simulation. The text and graphic information were designed to help. The information blocks that remained, though not deliberately planned or manipulated, were not excessive--many technical manuals, in fact, seem to have been designed to guard against comprehension. At some point, though, it would be desirable and feasible to manipulate some features of the program to assess effects of various kinds of information blocks. For example, it might be possible to reduce vocabulary difficulty at frames 10-11 by defining terms in context or in rebus, and to analyze whether that change reduced overall difficulty and requests for dictionary but had little effect on requests for graphics.

Or it might be possible to alleviate structural difficulty either by inserting in the surface text a minimal schematic showing the relationship of the key subassemblies or by "framing" with text. For example, we could add to the text "Earlier you made the back and added an axle. Now you will join the base to the axle at a right angle." Again, it would be possible to examine whether such changes affected not only overall difficulty but the kinds of information requested.

Not only can problems be reduced, they can deliberately be increased in order to understand their impact. To assess the effect of the segmented graphics (or rechecks or definitions), for example, that feature could be locked out. Or, to induce search, subjects might be directed to join two components that cannot at that point be joined. Over the long run it would obviously be useful to develop new tasks, but there are also advantages in systematic variations on well-mapped tasks, manipulating experimentally factors suggested by more naturalistic investigations of real or simulated tasks.

In order to understand the relationship of user, task, and technical information system, it will in the long run be necessary to categorize more precisely the types of the information blocks encountered. This will not be easy. As indicated earlier, one tactic that can be used in this effort is to construct and systematically vary types of information blocks. Even then, though, problems will remain. One is that an information block is to a certain extent an individual matter; one person may be unfazed while another is stopped. Yet by studying both group trends and individual responses we may be able to come to clearer understanding of the most common types of information blocks and the types of information that tend to resolve them. Similarly, each information block is to some extent situation-specific, conditioned by other features of the text and graphic environment. Yet we can abstract the generalizable factors from a variety of specific instances.

A third problem is that information is diffuse. If information is not available at one place it may be stated or inferrable at another place or in another format or in another modality (making the task easier for the user and harder for the researcher). Type and criticality of information block in a subtask may interact with availability of alternate sources in the information system and with user characteristics such as motivation, preference for various forms of information, and skill in constructing inferential networks.

Differences across Subjects

Subjects differed in the number of information requests they made. The total number of requests per subject ranged from o to 46, with a mean of 20. The number of requests for graphics per subject ranged from 0 to 27, with a mean of 11.

The number of requests for verbal information per subject ranged from 0 to 33, with a mean of 10. Subjects also varied in the patterning of their information requests. Some made few or no requests for information to supplement the text. Others, faced with an information block, quickly sought and received information from a single source. Others, faced with the same block, engaged in a multi-media search, a concatenation of graphics, defintions, and rechecks to previous text, all brought to bear on the problem.

The task in this study was straightforward, objective, constrained not only by the very directive directions, but by the very concrete materials--they could be assembled in only a limited number of ways, and yet there were times we wondered whether this was a projective test, a Rorschach in on-line graphics. At least some subjects seemed to use this task in a larger, self-defined task, acting out and testing some statements about themselves. One subject reported that she was mad at herself when she had to give in and ask for help. Similarly, another, also asking for information only when it was essential, and only after she'd completed a step, laughed when she recognized her own competitivness. Two other subjects mentioned they had been very careful not to make any mistakes, a goal not stressed by the researchers. Though no attempt was made to quantify these personal meanings, it is possible that these subjective interpretations and more objective metacognitions about when to stop seeking information and what sources are likely to be useful combine with learning strategy preference to form a problem space that the indivi-ual superimposes on the problem as defined by the investigator. It might be possible to induce greater conformity in approach, perhaps by emphasizing more strongly that the objective was to complete assembly of the loading cart with no errors, but that they could have as much time and as much information as they wanted. Yet at this stage we wanted to learn as much as we could about how people thought about the task.

On-line Problem Solving Strategies

To retrace the steps in problem-solving described earlier, in the input translation phase of the overall task an individual seems in general to accept the goal as defined in the program and the resources provided. For those with any experience along this line, the general nature of the assembly task is readily apparent, and relevant strategies are available. He or she may, however, fail to remember all of the potential information sources and may add constraints of his/her own, such as using as little information as possible or avoiding any errors or rechecks.

Selection and application of a problem solving method, constrained to some degree by the input translation of the information potential of the text, Hypertext, and concrete materials (and explicit directions) proceeds in this context by use of what is in sight or in memory, and by explicit selection of additional information from the computer-based technical information system. In this situation, it seems useful to treat together selection and application, although some subjects, because of their previous experience, may have been somewhat more inclined to select than able to apply information such as graphics. On the whole, though, these were able subjects and, on the molecular level, able to apply the information they selected. On a more molar level the method includes the subject's evaluation of the kind of information block, the information move(s) most likely to resolve it, and self-monitoring of the success of those efforts. On this level, not examined here, or even on the molecular level for less able subjects, it may be useful to separate selection and application and even to break down these steps further.

Regrouping may be seen in the application of varied information seeking methods to stubborn trouble spots, and hinted in the occasional sweeps back to an earlier frame. We have no direct record of any changes in a subject's

problem representation. There was no indication that subjects abandoned the attempt to solve any of the problems they encountered. Yet in a task such as this, an individual may be less than perfectly certain about one of the steps and may at some point pass on, even if some degree of uncertainty remains.

The generation of subgoals was not often seen(and would be hard to document if set aside). Within some complex concatenations of strategies, though, such a step in problem solving is suggested. One subject, for example, in attempting to solve the problem encountered at frame 5, rechecked to frames 3 and 4, recognizing after passing these points that there was need to disambiguate some terms or spatial orientations before the central goal of frame 5 could be achieved. Some of the sweeps backward during the exploration phase may reflect a return to subgoals set during the assembly task. A few subjects seemed either to pass a step in assembly with some unanswered questions or with a question about why they had at first failed to understand a point, and returned during the optional exploration period to reexamine the subgoal (of subjective sense of clear understanding) earlier set aside.

Experts on problem solving such as Newell and Simon (1972) or Shulman and Elstein (1975) invested many years, close analysis, and much thoughtful analysis and, undoubtedly, reconceptualization before presenting formal models of the process. We would not be so bold as to present a formal model at this point. The results we present here are only a beginning, and we have elected to start from the outside with objectively observable behavior, then gradually to circle closer.

Implications

Implications for Practice

Where users differ in preference and ability to process information in different formats and different levels of generality, it may be useful to include a variety of kinds of information in a technical information system for job aiding, and to allow subjects a high degree of control over information.

This is suggested by the increase in performance over previous studies and by the individual differences in number and kinds of information requested. It will, however, be important to test these factors more systematically than was attempted in this study.

Other implications for practice lie in combination of an internal tracking system and response analysis system, which can be used to develop individual response profiles, perhaps mapped against ideal or typical profiles, providing on-line Diagnostics of user's response patterns. These in turn can be linked to Adviser messages, intervention in the form of key information if the user seems lost, or signals to the trainer or supervisor. Cumulation of information selection patterns in a Debug subroutine across a relatively small number of subjects can help to spot potential problems and suggest remedies before courseware leaves the shop, reducing sharply the long range (Bunyard & Coward, 1982) costs.

Implications for Systematizing Knowledge about Job Aiding

Job aiding has drawn from laboratory research, instructional design folklore, and the designer's intuition. That's not good enough. In a period of rapidly changing technology many workers will be left out and many complex systems endangered unless job aiding systems, often computer-based, provide effective assistance. The knowledge currently available should be more systematically organized and the potent variables carefully tested in work-like tasks.

The job aiding procedure described in this study has promise as a base for assessing quite directly the effects of single variables and complex combinations. For example, it would be possible to test the effects of text only vs. segmented graphics only vs. overview graphics only, with and without the recheck option. Or to test a complex individually controlled

system like the one used here against an equally complex system controlled by the experimenter/trainer or program, based on response analysis or characteristics such as user's level of expertise or learning strategy preference.

The implications for construction of a theoretical base for design of job aiding are not in the results of this small study but in the possibilities it raises for alternation of integration of literature, synthesis, tentative model building, direct applications, and empirical testing of practically and theoretically important variables. The strongest argument for this approach is that it stays close to real problems and real people, reducing the ultimate difficulty of translating theory into practice. And while research on text processing has contributed to computer based job aiding, research on job aiding can contribute to research and practice in the broader field of technical literacy (Hutson, 1982).

Implications for Studying On-Line Problem Solving

This study has answered a few obvious questions, formulated a few less obvious questions, and provided a simple conceptualization of information blocks and information-search strategies as well as procedures for gathering, representing and analyzing relevant data. It has attempted to fit but not force these phenomena into a classic model of problem solving, with special emphasis on the information selection processes.

The TICCIT system's internal tracking system made it possible to record for each subject at each step the exact sequence of information selection, allowing some inferences about thought processes, based on subjects' profiles, observer's notes, and informal debriefing. One future direction is to obtain from some subjects a verbal protocol as they work. While it's possible that the verbal protocol would change the task, the objective record of information moves could be compared to profiles obtained without the

think-aloud feature. The verbal protocols should be especially helpful in determining users' problem representations and metacognitions, enriching our interpretations of the more easily quantified machine-recorded responses.

Another possible direction is to provoke awareness of search processes by violating expectations. Just as social conventions are most likely to be made explicit by the response when they are violated, thought processes may be most sharply defined when a subject finds his/her expectations violated. In the present study, the information in text and graphics was congruent and complementary, and the sequence reasonable. But it would be easy to insert a few points where there was a contradiction or apparent contradiction between text and graphics or between two lines in the text. Another possibility would be to violate constraints on sequence, e.g., directing subjects to unite one sub-assembly to another that has not yet been assembled. In resolving these problems, subjects might make more visible their thought processes.

From this point there are a number of different paths that could be explored in studying on-line search processes, and we hope that others will join us in this exploration.

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Acknowledgments

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Table 1

Types of Information Moves by Each Subject

Subject	Forward	Reverse	Definition	Total Verbal	Segmented Graphic	Overview Graphic	Total Graphic	TOTAL
1	3	3	2	(5)	8	4	(12)	17
2	0	0	1	(1)	6	1	(7)	8
3	6	6	10	(16)	8	0	(8)	24
4	4	4	1	(5)	18	6	(24)	29
5	8	8	8	(16)	5	0	(5)	21
6	1	1	2	(3)	12	0	(12)	15
7	0	0	0	(0)	0	0	(0)	0
8	0	0	7	(7)	5	3	(8)	15
9	0	0	10	(10)	17	0	(17)	27
10	0	0	1	(1)	15	0	(15)	16
11	1	1	11	(12)	2	1	(3)	15
12	2	2	17	(19)	3	2	(5)	24
13	0	0	19	(19)	18	9	(27)	46
14	0	0	1	(1)	10	0	(10)	11
15	0	0	2	(2)	16	1	(17)	19
16	2	2	3	(5)	2	2	(4)	9
17	3	3	8	(11)	12	1	(13)	24
18	5	5	5	(10)	13	2	(15)	25
19	5	5	12	(17)	4	5	(9)	26
20	2	2	31	(33)	3	0	(3)	36
	42	42	151	(193)	177	37	(214)	407

Table 2

Frequency of Various Types of Information Searches

n=20

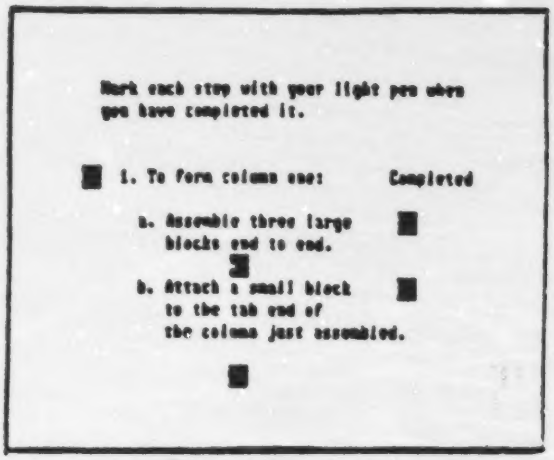
	Moves from frame	Information moves to each frame				
Frame	Forward	Reverse	Defintions	Segmented Graphics	Overview Graphics	TOTAL
1	2	0	7	12	1	(20)
2	5	1	2	6	0	(9)
3	5	4	4	5	2	(15)
4	9	4	5	14	8	(31)
5	3	9	24	28	4	(65)
6	1	3	5	6	3	(17)
7	4	2	6	14	1	(23)
8	0	4	1	5	3	(13)
9	4	0	7	15	4	(26)
10	2	5	13	19	5	(42)
11	1	3	26	20	1	(50)
12	4	1	9	11	0	(21)
13	0	4	3	10	0	(17)
14	0	0	8	11	0	(19)
15	2	0	1	1	0	(2)
16	0	2	30	0	5	(37)
TOTAL	42	42	151	177	37	(407)
Mean (rounded)	21	21	76	89	2	20

Table 3

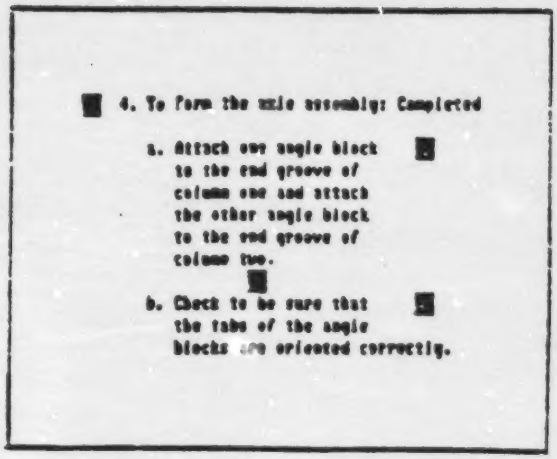
Number of Rechecks Staring and Ending at Various Frames

Frame	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rechecks starting at this frame	0	1	4	4	9	3	2	4	0	5	3	1	4	0	0	2
Rechecks ending at this frame	2	5	5	10	2	1	4	0	4	2	1	4	0	0	2	0

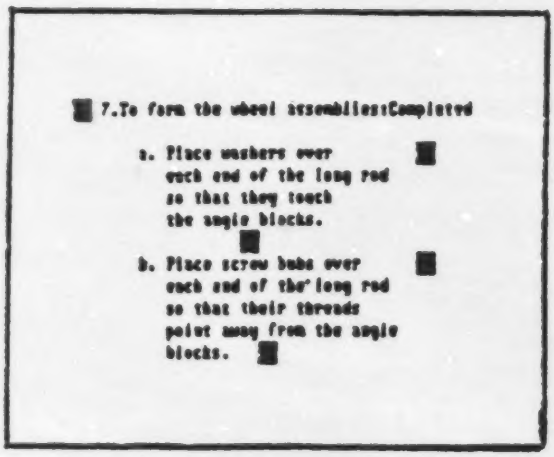
Figure 1. Examples of steps in surface text


Mark each step with your light pen when you have completed it.
1. To form column one: Completed
a. Assemble three large blocks end to end.
b. Attach a small block to the tab end of the column just assembled.

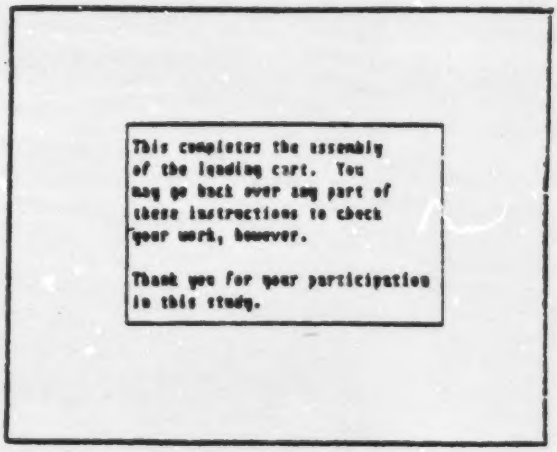
Step 1


4. To form the angle assembly: Completed
a. Attach one angle block to the end groove of column one and attach the other angle block to the end groove of column two.
b. Check to be sure that the tabs of the angle blocks are oriented correctly.

Step 5


7.To form the wheel assemblies:Completed
a. Place washers over each end of the long rod so that they touch the angle blocks.
b. Place screw bobs over each end of the long rod so that their threads point away from the angle blocks.

Step 11


This completes the assembly of the loading cart. You may go back over any part of these instructions to check your work, however.
Thank you for your participation in this study.

Step 17

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Figure 2. Examples of definitions

"Attach" means connect or assemble end to end.

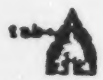
211

"Washers" refer to the two small red circular plastic pieces with a serrated edge.

Washer

304

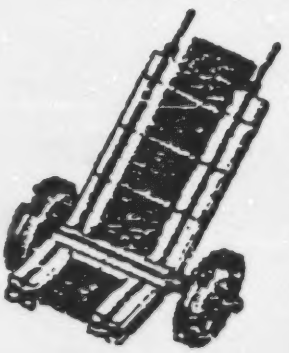
"use angle block" as shown below:



Angle block

504

Note the location of the handles in the graphic. Each handle is inserted at the end of the model with exposed tabs and in the grooves at the front.



622

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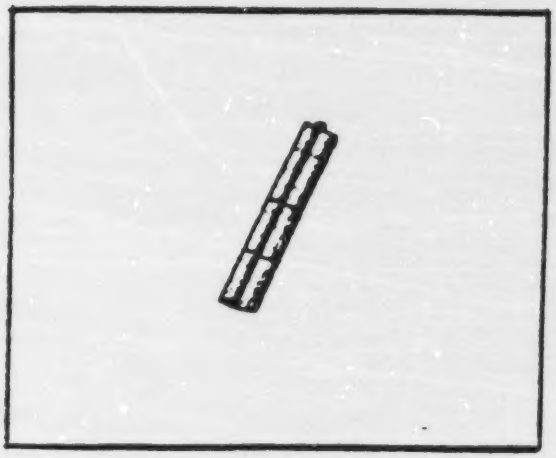
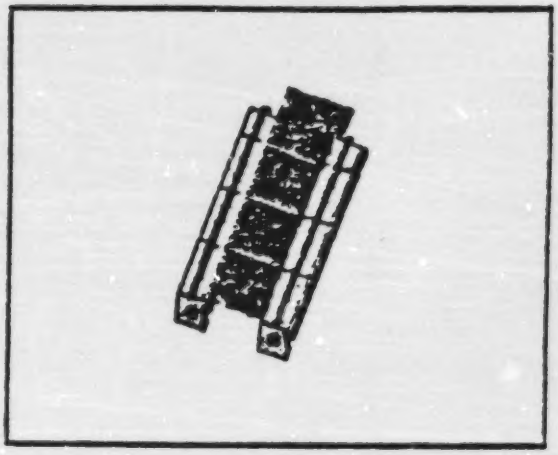
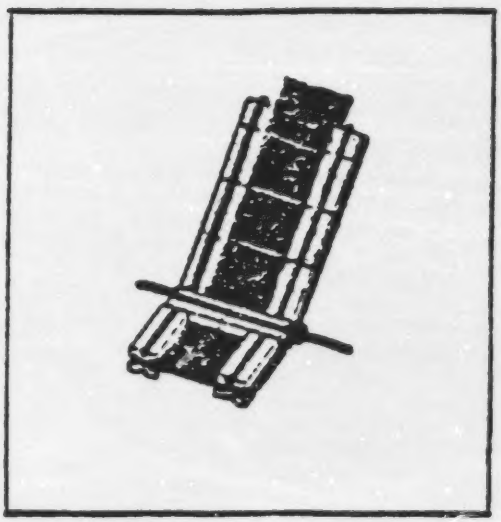
Figure 3. Examples of graphics



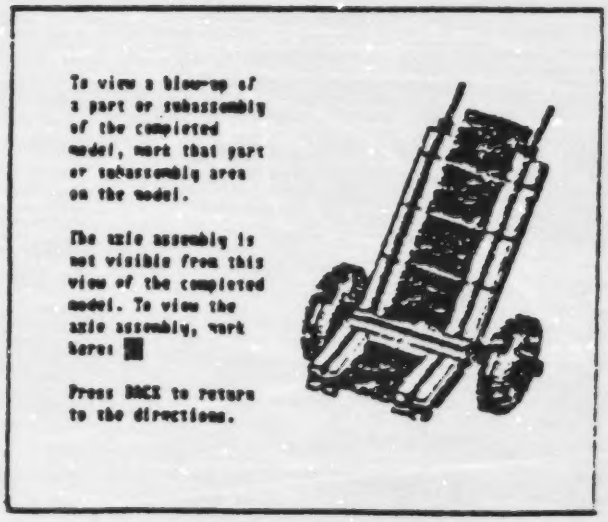
701



710



719


To view a blow-up of a part or subassembly of the completed model, mark that part or subassembly area on the model.
The axle assembly is not visible from this view of the completed model. To view the axle assembly, mark here:
Press BACK to return to the directions.

727

BEST COPY AVAILABLE

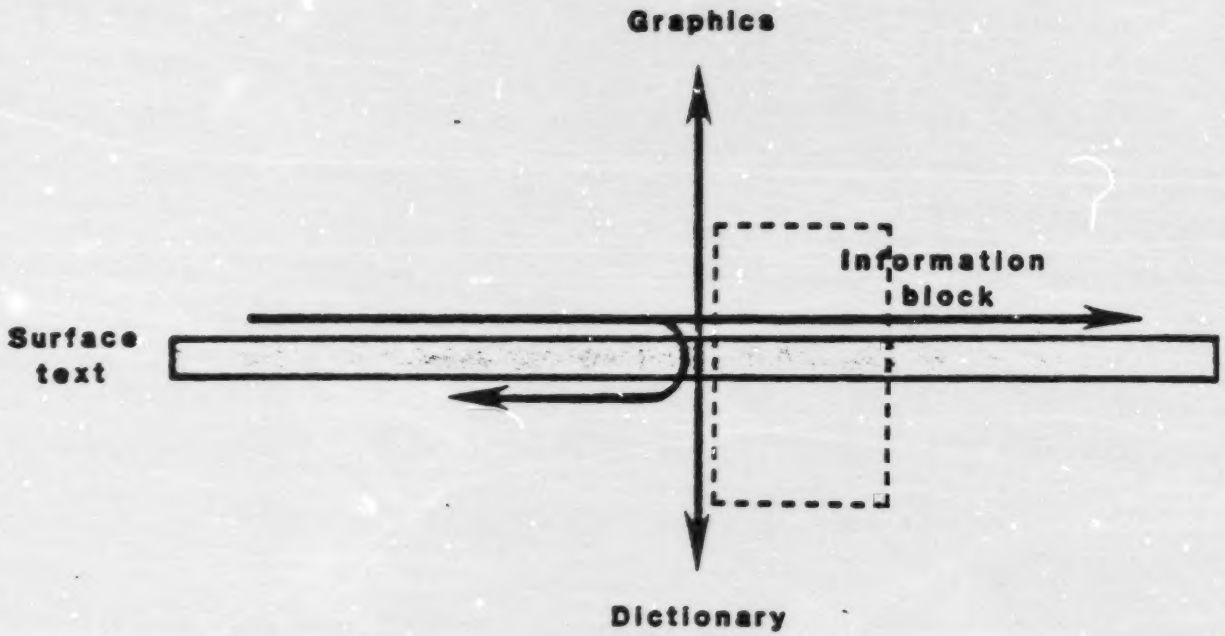


Figure 4. A schematic representation of the information search strategies for resolving an information block when Hypertext display is available. Options include moving forward, moving up to a graphic overview, down to clarification of a specific term, or rechecking the surface text or Hypertext.

FIGURE 5

Percent of Requests for Various Information Sources
Across All Subjects and All Frames

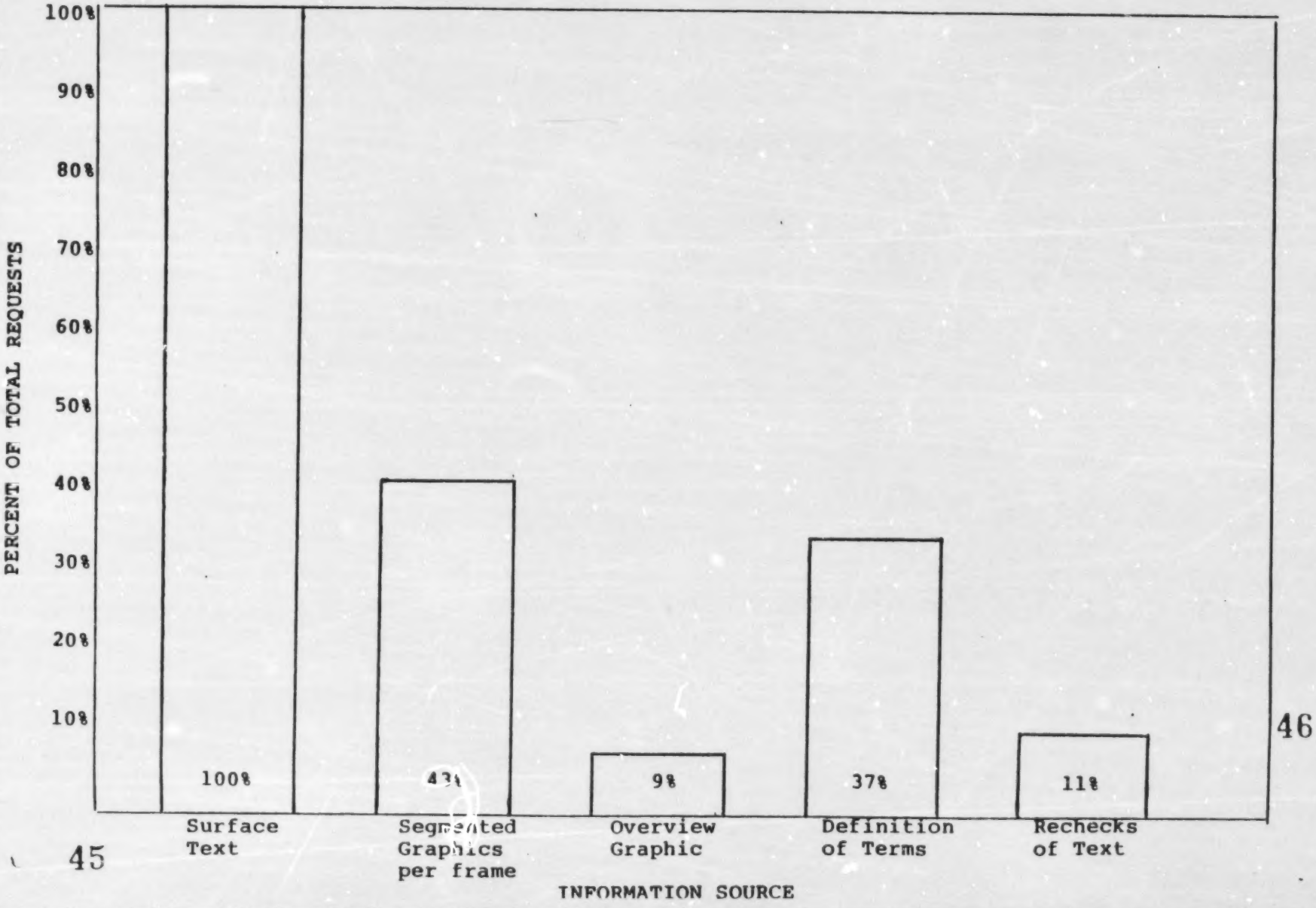


Figure 6

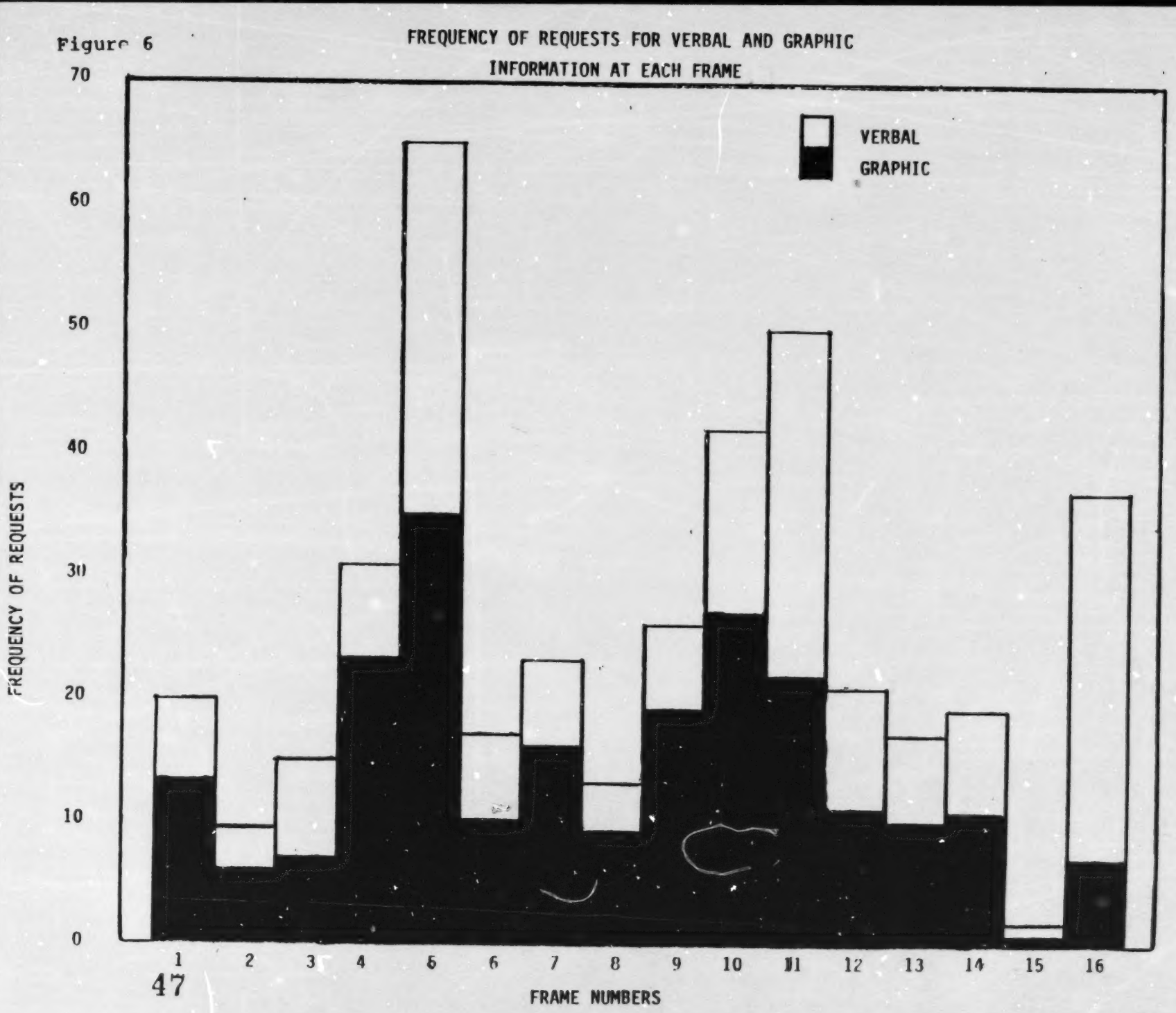
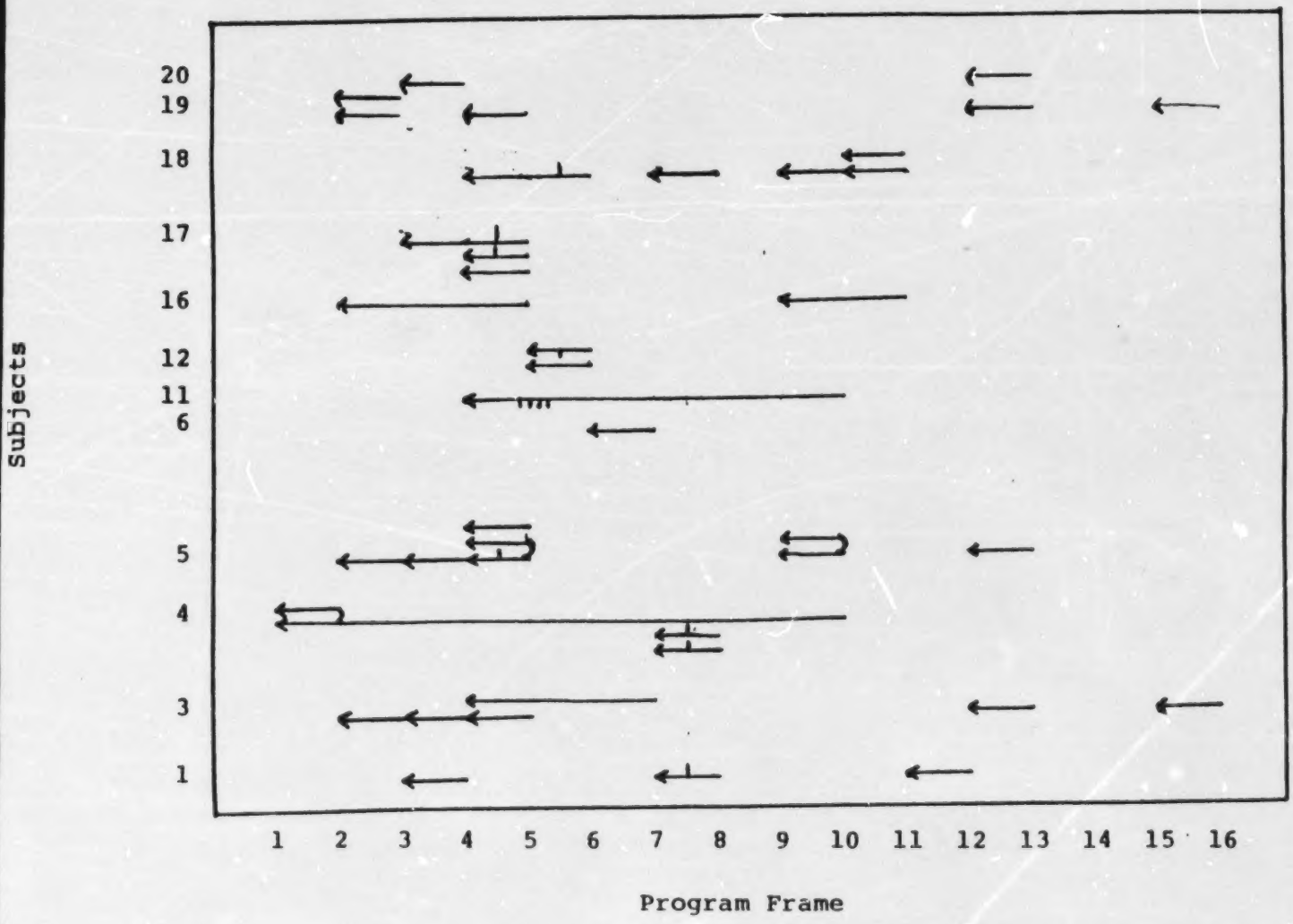

FREQUENCY OF REQUESTS FOR VERBAL AND GRAPHIC INFORMATION AT EACH FRAME
VERBAL
GRAPHIC
FREQUENCY OF REQUESTS
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
FRAME NUMBERS

Figure 7

Patterns of Rechecks To and From Various Program Frames



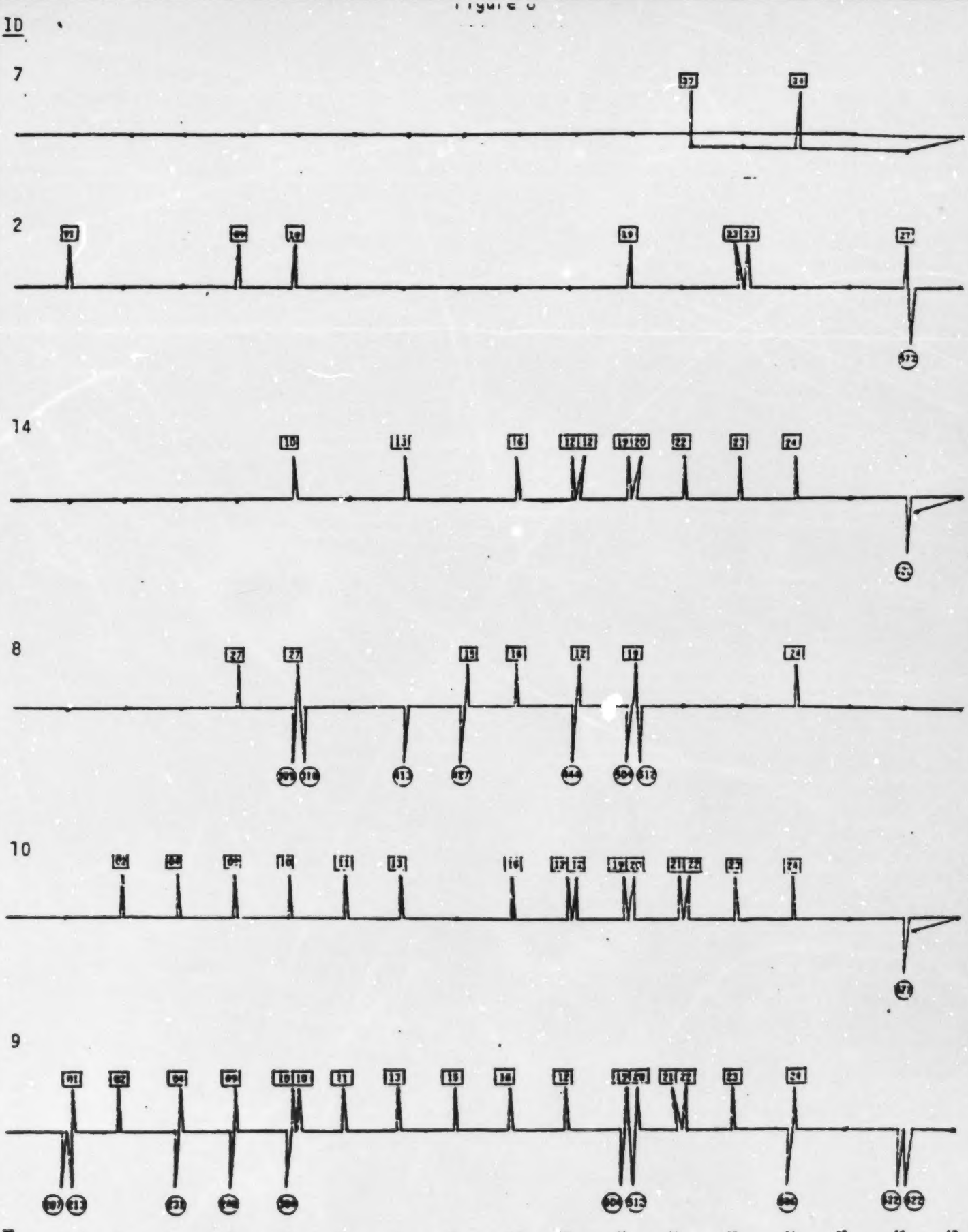

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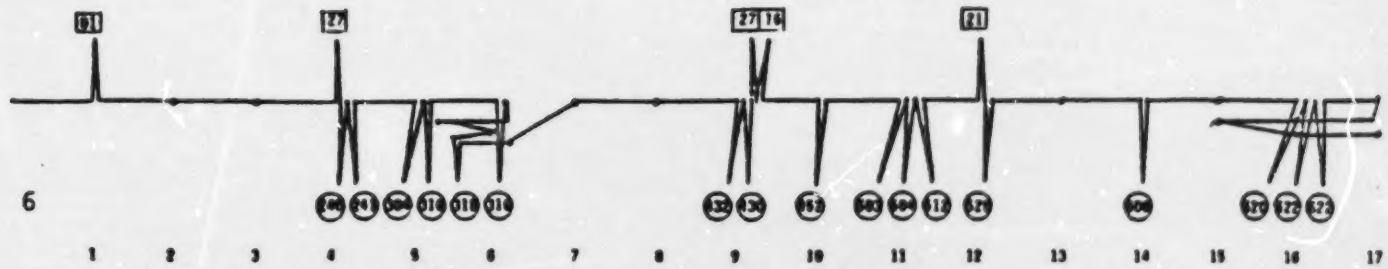
Figure 9

12



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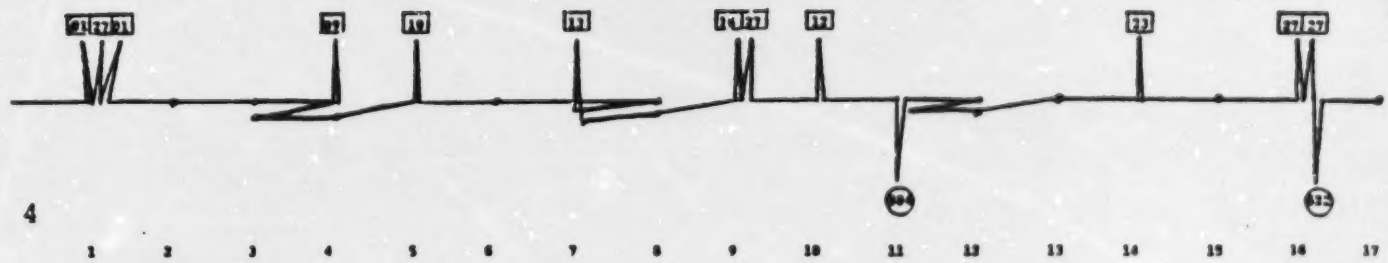

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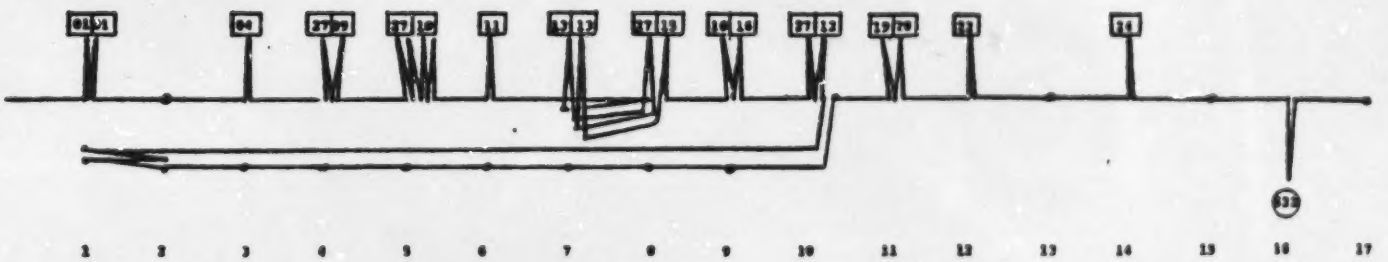

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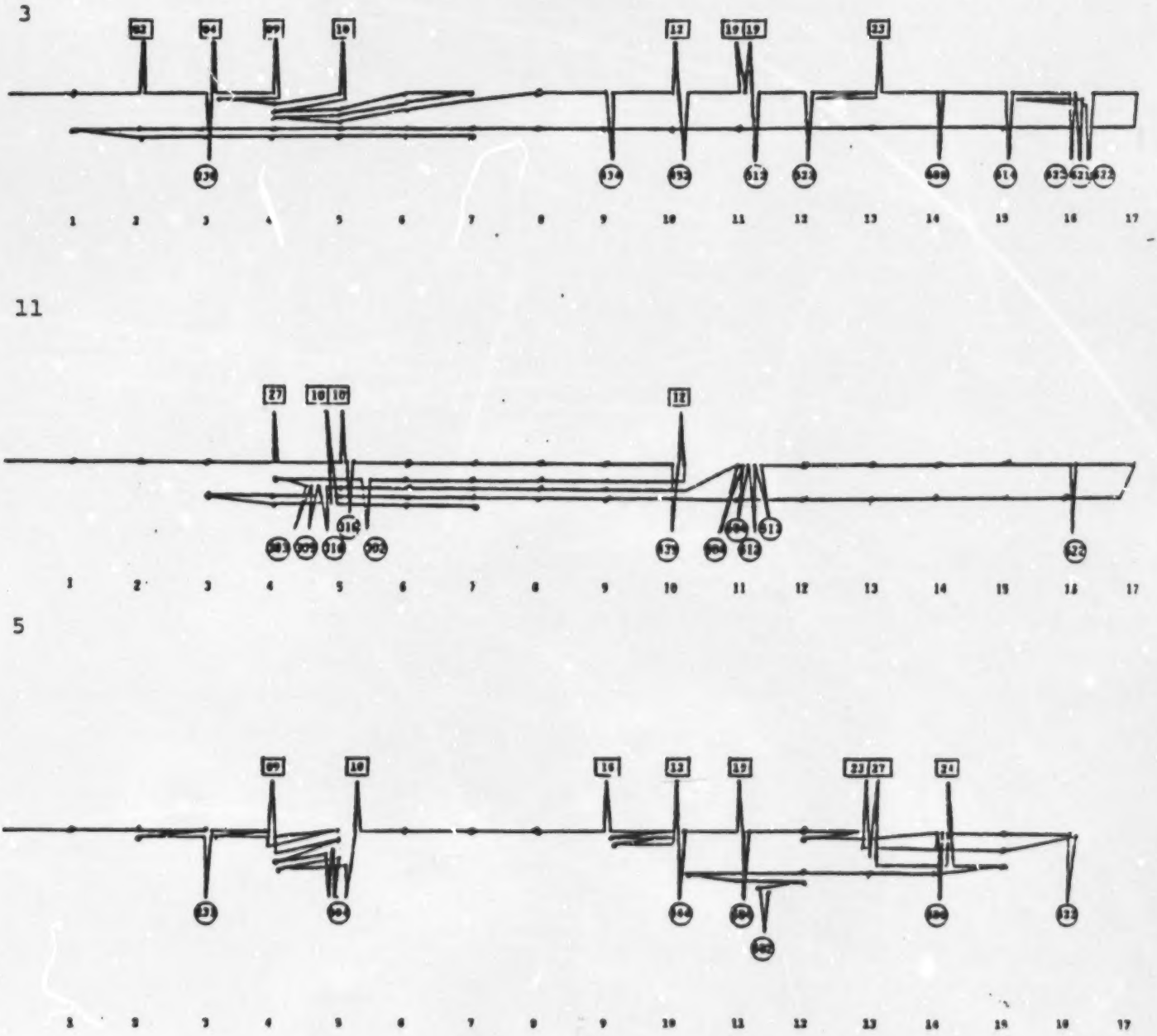
Figure 10



Addendum

Frequency of Various Types of Information Searches-- Community College

n=37

Frame	Forward	Reverse	Definitions	Total Verbal	Segmented Graphics	Overview Graphics	Total Graphics	TOTAL
1	2	0	25	(25)	29	7	(36)	61
2	0	2	8	(10)	12	2	(14)	24
3	3	0	14	(14)	21	1	(22)	36
4	1	3	22	(25)	29	20	(49)	74
5	2	1	24	(25)	45	6	(51)	76
6	3	2	5	(7)	30	2	(32)	39
7	2	3	4	(7)	37	3	(40)	47
8	2	2	2	(4)	26	2	(28)	32
9	2	2	1	(3)	37	0	(37)	40
10	3	2	9	(11)	36	1	(37)	48
11	3	3	48	(51)	80	1	(81)	132
12	1	2	8	(10)	56	2	(58)	68
13	0	3	10	(13)	31	0	(31)	44
14	1	0	9	(9)	28	1	(29)	38
15	2	0	2	(2)	11	0	(11)	13
16	2	2	56	(58)	0	12	(12)	70

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